EXAMPLES OF THE PERFORMANCE OF THE ELECTRO-MAGNETIC ENGINE*

SOME experiments and conclusions I arrived at a quarter of a century ago having been recently criticised, I have thought it might be useful to place the subject of work in connexion with electro-magnetism in a different and I hope clearer form than that in which I have hitherto placed it. The numbers given below are derived from recent experiments.

Suppose an electro-magnetic engine to be furnished with fixed permanent steel magnets, and a bar of iron made to revolve between the poles of the steel magnets by reversing the current in its coil of wire. Such an arrangement is perhaps the most efficient, as it is the most simple form of the apparatus. In considering it, we will first suppose the battery to consist of 5 large Daniell's cells in series, so large that their resistance may be neglected. We will also suppose that the coil of wire on the revolving bar is made of a copper wire 389 feet long, and $\frac{1}{16}$ of an inch diameter, or offering a resistance to one BA unit. Then, on connecting the terminals of this wire with the battery, and keeping the engine still, the current through the wire will be such as, with a horizontal force of earth's magnetism 3·678, would be able to deflect the small needle of a galvanometer furnished with a single circle of one foot diameter, to the angle of 54°23′. Also this current going through the above wire for one hour will evolve heat that could raise 110·66 lbs. of water 1°, a quantity equal to 85430 ft. lbs. of work. In the meantime the zinc consumed in the battery will be 535·25 grains. Hence the work due to each grain of zinc is 159·6 ft. lbs., and heat ·20674 of a unit.

I. In the condition of the engine being kept still we have therefore, current being 1·396, as shown by a deflection of 54° 23′,

1. Heat evolved per hour by the wire 110·66 units.
2. Consumpuion of zinc per hour 535·25 grains.
3. Heat due to 535·25 grains, 110·66 units.
4. Therefore the work per hour will be (110·66 -- 110·66) 772=0.
5. And the work per grain of zinc will be $\frac{0}{535\cdot25}$=0.

II. If the engine be now started and kept by a proper load to a velocity which reduces the current to $\frac{2}{3}$, or ·9307, indicated by deflection 42° 57′, we shall have

1. Heat evolved per hour by the wire 110·66 × $\left\{\frac{2}{3}\right\}$ = 49·18 units.
2. Consumption of zinc per hour 535·25 × $\frac{2}{3}$ = 356·83 grains.
3. Heat due to 356·83 grains, 110·66 × $\frac{2}{3}$ = 73·77 units.
4. Therefore the work per hour will be (73·77 − 49·18) 772 = 18983 ft. lbs.
5. And the work per grain of zinc will be $\frac{18983}{356\cdot83}$ = 53·2 or $\frac{1}{3}$ of the maximum.

III. If the load be lesssened until the current is reduced to $\frac{}{2}$ of the original amount, or to ·698, we shall have

1. Heat evolved per hour by the wire 110·66 × $\left(\frac{1}{2}\right)^2$ = 27·665 units.
2. Consumption of zinc per hour 535·25 × $\frac{1}{2}$ = 267·62 grains.
3. Heat due to 267·62 grains 110·66 × $\frac{1}{2}$ = 55·33.
4. Therefore the work per hour will be (55·33 − 27·665) 772 = 21357.
5. And the work per grain of zinc will be $\frac{21357}{267\cdot62}$ = 79·8 or $\frac{1}{2}$ of the maximum duty.

IV. If the load be still further reduced and velocity increased so as to bring down the cnrrent to $\frac{1}{3}$ of what it was when the engine was still, or to ·4653, shown by a deflection of the galvanometer of 24° 57, we shall have

1. Heat evolved per hour by the wire 110·66 × $\left(\frac{1}{3}\right)^2$ = 12·294 units.
2. Consumption of zinc per hour 535·25 × $\frac{1}{3}$ = 178·42 grains.
3. Heat due to 178·42 grains 110·66 × $\frac{1}{3}$ = 36·89 units.
4. Therefore the work per hour will be (36·89 − 12·294) 772 = 18988 ft. lbs.
5. And the work per grain of zinc will be $\frac{18988}{178\cdot42}$ =106·4 or $\frac{2}{3}$ of the maximum duty.

V. Remove the load still further until the velocity increases so much that the current is brought down to $\frac{1}{100}$ of its quantity when the engine is still. Then we shall have

1. Heat evolved per hour by the wire 110·66 × $\left(\frac{1}{100}\right)^2$ = ·011066 of a unit.
2. Consumption of zinc per hour 535·25 × $\frac{1}{100}$ = 5·3525 grains.
3. Heat due to 5·3525 grains of zinc 110·66 ×$\frac{1}{100}$= 1·1066 units.
4. Therefore the work per hour will (1·1066 – ·011066)772 = 845·73 ft. lbs.
5. And the work per grain of zinc will be $\frac{845\cdot73}{5\cdot352}$ = 158 or $\frac{99}{100}$ of the maximum duty.

When the velocity increases so that the current vanishes the duty=159·6.

I. Let us now improve the engine by giving it a coil of 4 times the conductivity, which will be done by using a copper wire 389 feet long and $\frac{1}{8}$ of an inch diameter, the same battery being used as before. Then when the engine is kept still, we shall have a current 1·396 × 4 = 5·584, shown by a deflection of 79° 51′. Then we shall have

1. Heat evolved per hour by the wire 110·65 × $\frac{4^2}{4}$= 442·64 units.
2. Consumption of zinc per hour 535·25×4=2141 grains.
3. Heat due to 2141 grains 442·64 units.
4. Therefore the work per hour will be (442·64 – 442·64) 772=0.
5. And the work per grain of zinc will be $\frac{0}{2141}$=0

II. Start the engine with such a load as shall reduce the current to $\frac{2}{3}$, or to 3·7227 (74° 58′), then we shall have

1. Heat evolved per hour by the wire 442·64 × $\left(\frac{2}{3}\right)^2$ = 196·73 units.
2. Consumption of zinc per hour 2141 × $\frac{2}{3}$ = 1427·3 grains.
3. Heat due to 1427·3 grains 442·64 × $\frac{2}{3}$ =295·09 units.
4. Therefore the work per hour will be (295·09 − 196·73) 772 = 75934.

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* From the Proceedings of the Manchester Literary and Philosophical Society.

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5. And the work per grain of zinc will be $\frac{75934}{1427{\cdot}3} = 53{\cdot}2$ or $\frac{1}{3}$ of the maximum duty.

III. Lessen the load so that the velocity of the engine is increased until the current is reduced to one half its original amount, or 2·792 shown on the galvanometer by a deflection of 70° 18′. Then we shall have

1. Heat evolved per hour by the wire $442.64 \times \left(\frac{1}{2}\right)^2 =$ 110·66 units.
2. Consumption of zinc per hour $2141 \times \frac{1}{2} = 1070{\cdot}5$ grains.
3. Heat due to 1070·5 grains, $442{\cdot}64 \times \frac{1}{2} = 221{\cdot}32$ units.
4. Therefore the work per hour will be $(221{\cdot}32 - 110{\cdot}66)\ 772 = 85430$ ft. lbs.
5. And the work per grain of zinc will be $\frac{85429}{1070{\cdot}5} = 79{\cdot}8$ or $\frac{1}{2}$ the maximum duty.

IV. Let the load be further reduced until the velocity reduces the current to $\frac{1}{3}$, or to 1·8613 shown by a deflection of 61° 45′. Then we shall have

1. Heat evolved per hour by the wire $442{\cdot}64 \times \left(\frac{1}{3}\right)^2 =$ 49·182 units.
2. Consumption of zinc per hour $2141 \times \frac{1}{3} = 713{\cdot}66$ grains.
3. Heat due to 713·66 grains of zinc $442{\cdot}64 \times \frac{1}{3} = 147{\cdot}55$ units.
4. Therefore the work per hour will be $(147{\cdot}55 - 49{\cdot}182)\ 772 = 75940$ ft. lbs.
5. And the work per grain of zinc will be $\frac{75940}{713{\cdot}66} = 106{\cdot}4$ or $\frac{2}{3}$ of the maximum duty.

V. Let the load be still further reduced until, with the increased velocity, the current becomes reduced to $\frac{1}{100}$, or to ·05584 showing a deflection of 3° 12′. Then we shall have

1. Heat evolved per hour by the wire $442{\cdot}64 \times \left(\frac{1}{100}\right)^2 = {\cdot}044264$ of a unit.
2. Consumption of zinc per hour $2141 \times \frac{1}{100} = 21{\cdot}41$ grains.
3. Heat due to 21·41 grains of zinc $442{\cdot}64 \times \frac{1}{100} = 4{\cdot}4264$ units.
4. Therefore the work per hour will be $(4{\cdot}4264 - {\cdot}04426)\ 772 = 3383$ ft. lbs.
5. And the work per grain of zinc will be $\frac{3383}{21{\cdot}41} = 158$ or $\frac{99}{100}$ of the maximum duty.

Now suppose that we still further improve our engine by making the stationary magnets twice as powerful. In this case all the figures will remain exactly the same as before, the only difference being that the engine will only require to go at half the velocity in order to reduce the current to the same fraction of its first quantity. The attraction will be doubled, but the velocity being halved no change will take place in the amount of work given out.

In all cases the maximum amount of work per hour is obtained when the engine is going at such a velocity as reduces the current to one half of its amount when the engine is held stationary; and in this case the duty per grain of zinc is one half of the theoretical maximum.

The same principles apply equally well when, instead of employing the machine as an engine evolving work, we do work on it by forcibly reversing the direction of its motion. Suppose for instance we urge it with this reverse velocity until the quantity of current is quadrupled, or becomes 22·386 indicated by a deflection 87° 26′. Then we shall have

1. Heat evolved per hour by the wire $442{\cdot}64 \times 4^2 = 7082{\cdot}2$ units.
2. Consumption of zinc per hour $2141 \times 4 = 8564$ grains.
3. Heat due to 8564 grains of zinc $442{\cdot}64 \times 4 = 1770{\cdot}56$ units.
4. Therefore the work per hour will be $(1770{\cdot}56 - 7082{\cdot}2)\ 772 = -4100432$ ft. lbs.
5. And the work per grain of zinc will be $\frac{-4100432}{8564} = -478{\cdot}8$ or -3 times the maximum working duty.

The principal reason why there has been greater scope for the improvenmt of the steam engine than for the electro-magnetic engine arises from the circumstance that in the formula $\frac{a-b}{a}$, applied to the steam engine by Thomson, in which a and b are the highest and lowest temperatures, these values are limited by practical difficulties. For a cannot easily be taken above $459° + 374° = 833°$ from absolute zero, since that temperature gives 12·425 atmospheres of pressure, nor can b be readily taken at less than the atmospheric temperature or $449° + 60° = 519°$. Also there is much difficulty in preventing the escape of heat; whereas the insulation of electricity presents no difficulty,

I had arrived at the theory of the electro-magnetic engine in 1840, in which year I published a paper in the 4th Vol. of Sturgeon's Annals, demonstrating that there is "no variation in economy, whatever the arrangement of the conducting metal, or whatever the size of the battery." The experiments of that paper indicate 36 ft. lbs. as the maximum duty for a grain of zinc in a Wollaston battery. Multiplying this by 4 to bring it to the intensity of a Daniell's battery, we obtain 144 foot lbs. Here, as in the experiments in the paper on Mechanical Powers of Electro-Magnetism, Steam, and Horses, the actual duty is less than the theoretic; which is owing partly to the pulsatory nature of the current, and partly also to induced currents giving out heat in the substance of the iron cores of the electro-magnets; although these last were obviated as far as possible by using annealed tubes with slits down their sides.

J. P. JOULE

OBJECT TEACHING AND SCIENCE IN AMERICA

THE following article, reprinted from the *Scientific American*, will give some idea of the spirit in which the teaching of science is being pursued in the United States:—

"The public are beginning to be awakened to the fact that technical education is *the* education they require, being in accordance with the conditions of modern civilisation; and it is admitted that such technical education must be based upon a foundation of natural knowledge. The principles of the natural sciences must then, for the future, form an essential part of popular education; the only questions are, how far and in what manner are these sciences to be introduced? Whatever is to be the amount taught, educators are agreed that the first steps in natural science, or, in other words, in systematising natural knowledge, are to be taken as early as possible. Early impressions are the deepest, and every child before its school days is already an untrained student of nature. The foundations of technical education should, therefore, be laid in the primary school; but whether commenced thus early or not, the method will always be the same. The child must be encouraged and guided in its natural habits of observing, and it must be led to systematise its observations, connecting them together by a chain of reasoning into groups of related ideas. This method is simply that known as "object teaching;" and you may as well try to fly without wings, or to teach geography without maps or globes, as to teach natural science without objects and diagrams. There is not a teacher, nowadays, but has heard of this object teaching; there are hundreds who have tried to utilise it; there are

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